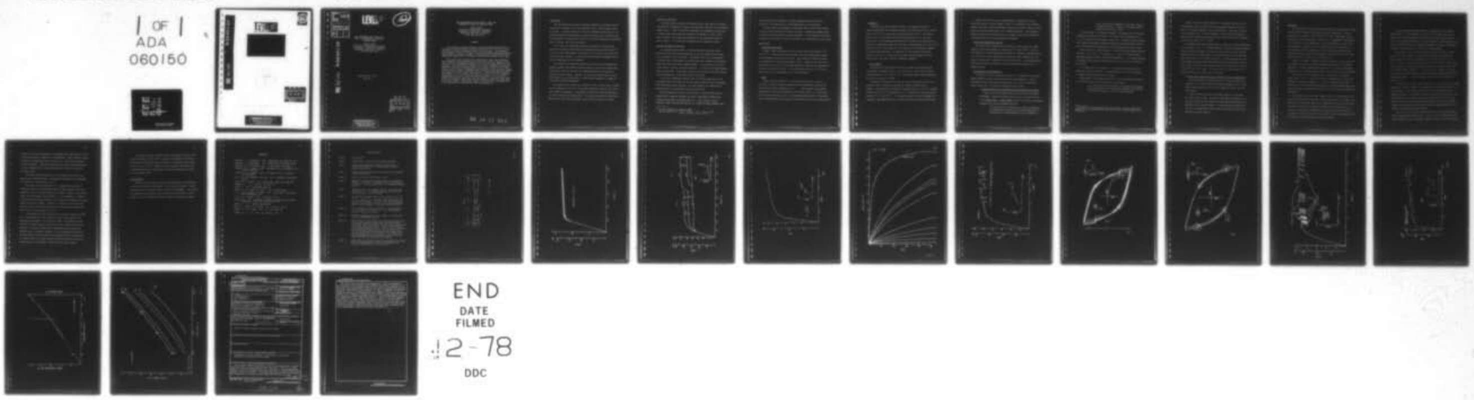
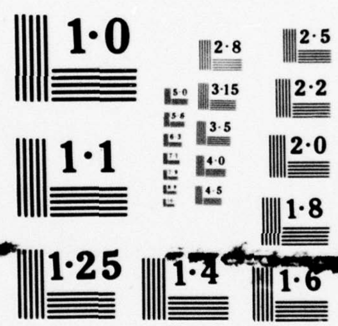
AD-A060 150 RENSSELAER POLYTECHNIC INST TROY N Y DEPT OF MECHANI--ETC F/G 11/6
ROOM TEMPERATURE RATE SENSITIVITY, CREEP, AND RELAXATION OF TYP--ETC(U)
JUL 78 E KREMPL N00014-76-C-0231
UNCLASSIFIED RPI-CS-78-5 NL

1 OF 1
ADA
060150



END
DATE
FILMED
12-78
DDC



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Rensselaer Polytechnic Institute

Troy, New York 12181

LEVEL II

(12)

ROOM TEMPERATURE RATE SENSITIVITY, CREEP, AND RELAXATION OF TYPE 304 STAINLESS STEEL

Erhard Krempl
Department of Mechanical Engineering, Aeronautical Engineering & Mechanics
Rensselaer Polytechnic Institute
Troy, New York 12181

Report No. RPI CS 78-5

July 1978

ROOM TEMPERATURE RATE SENSITIVITY, CREEP, AND RELAXATION OF TYPE 304 STAINLESS STEEL

Erhard Krempl
Department of Mechanical Engineering,
Aeronautical Engineering & Mechanics
Rensselaer Polytechnic Institute
Troy, New York 12181

ABSTRACT

The uniaxial viscoplastic behavior of Type 304 stainless steel was investigated by tensile tests at various strain rates (10^{-8} to 10^{-2} s^{-1}), and by short-term creep and relaxation tests up to five hours. Instantaneous large changes in strain rate (strain-rate history effects) were also performed during monotonic and cyclic loading. A servocontrolled testing machine and displacement measurement on the specimen gage length were used for all tests.

The results show significant rate sensitivity, creep, and relaxation. Test histories involving loading and unloading with positive loads up to 15% strain show that the relaxation behavior in the plastic range depends only on the strain rate preceding the relaxation test and is independent of the strain magnitude. Also, the relaxation behavior is uniquely related to the stress changes corresponding to instantaneous large changes in the strain rate during tensile tests. Completely reversed strain controlled loading gradually changes the stress-change strain-rate-change behavior. Annealed specimens and specimens loaded to a cyclic steady state differ not only in their work hardening characteristic but also in their rate-dependent behavior. In the cyclic steady state different hysteresis loops are traced for different strain rates with fully reversible transitions from one hysteresis loop to the other under strain-rate changes. These results support the notion that viscoplasticity can be represented by piecewise nonlinear viscoelasticity.

INTRODUCTION

The room-temperature inelastic deformation behavior of structural metals is generally considered to be rate-independent by the "yield surface" school of thought. In "dynamic plasticity" the rate-independent idealization is not always accepted and rate-dependent constitutive equations are frequently used. This difference in viewpoint may be due to the different experimental techniques used in "dynamic" and "static plasticity".

In the last case "dead load" machines or screw-driven (hydraulically actuated) universal testing machines are employed and the accurate control of the rate of load (displacement) application is very difficult with these conventional testing machines. In the former special testing techniques such as the split Hopkinson bar were developed.

The situation has completely changed with the advent of servocontrolled testing equipment which permits accurate control of the rate of loading under quasi-static conditions and which are frequently employed in fatigue and fracture mechanics testing. However, very little use has been made of these test machines in the determination of stress-strain properties in support of constitutive equation development.

The present study utilizes such equipment for the uniaxial state of stress at room temperature with the aim of providing experimental support for constitutive equation development. Considerable rate-effects, creep, and relaxation are found for Type 304 Stainless Steel. The results also show that this metal behaves like a nonlinear viscoelastic solid in certain regions of loading.

MATERIAL AND SPECIMEN

The test material was Type 304 Stainless Steel, taken from the "reference heat 9T 2796"[1]. Specimens cut from the bar stock were machined to the dimensions shown in Fig.1. Prior to testing the specimens were annealed by sealing them in Argon filled quartz tubes and subjecting the assembly to 2000°F (1093°C) for 90 minutes. The stress-strain diagrams of four annealed specimens are shown in Fig.2. It is seen that the properties are reasonably uniform.

TESTING EQUIPMENT AND PROCEDURE

All specimens were tested in an MTS servocontrolled tension-torsion system with dual ramp function generator and the test results were recorded on an Esterline Augus XY recorder. Displacement was in all cases measured by an MTS clip-on extensometer on the gage length and converted to engineering strain and strain rate using standard methods. In the following we refer to stress (strain) control, creep, and relaxation. In actuality the load (displacement) is controlled. During creep the load is kept constant and during relaxation the displacement in the gage length is held fixed.

The clip-on extensometer together with the function generator and the servocontrolled system enable an accurate strain control which is not possible with conventional testing set-ups. By simply changing the command signal stress control can be achieved in the same test set-up.

We have basically two sets of test histories, repeated loading and unloading with no negative stresses; and cyclic, completely reversed strain controlled histories at an amplitude of .4%. Each history is either piecewise linear (ramp forcing function) or consists of creep (constant load

---

1) The test material was donated by ERDA.
Chemical composition: .044 C, 1.26 Mn, .033 P, .016 S, .45 Si, 9.50 Ni, 18.64 Cr, .34 Mo, .25 Cu.

forcing function) or relaxation (constant displacement forcing function) intervals. All tests were run at room temperature in air environment.

In some cases the extensometer was rezeroed before the test was restarted. If this is so the prestrain is noted on the graph. Engineering stresses based on the original cross section are used throughout. In some graphs we have shown a schematic of the input function to facilitate the interpretation of the results.

TEST RESULTS

Strain-Rate Sensitivity

Figure 3 shows three tensile tests at strain rates ranging from 10^{-2} s^{-1} to 10^{-8} s^{-1}. In two of the tests the strain rate was instantaneously changed by three orders of magnitude at points A. The subsequent increase in stress is reminiscent of the strain-rate history effect. Except for the curve with a final strain rate of 10^{-2} s^{-1} the slope immediately following the instantaneous change in strain rate is elastic. (The shallow slope for the 10^{-2} s^{-1}-curve may be due to the slow response time of the XY-recorder.)

Creep

Figure 4 shows the results of a stress-controlled test at a rate of 283 psi/s [1.95 MPa/s] where the stress was held intermittently constant for five minutes at points labelled 1,2,3,4 .... . The horizontal lines measure the amount of creep occurring during the five-minute period. The creep strain vs time curves are shown in Fig.5. The accumulated creep strain is increasing with increasing stress and is certainly not negligible at the high stress levels.

Relaxation

A specimen with prior mechanical history (9% prestrain) involving loading and unloading (but no negative stresses) was first subjected to a strain rate of $10^{-5}\ s^{-1}$ with intermittent relaxation periods of 30 s. The vertical bars in Fig.6 show the amount of stress relaxation during a 30 s interval. Beyond point C the relaxation period commences at points B and lasts for 600 s. Between the relaxation periods the strain rate is varied between 10^{-6} and $10^{-3}\ s^{-1}$. The data in Fig.6 clearly shows the rate sensitivity of the material together with significant relaxation. By comparing the total stress change during relaxation in 600 s it is seen that the relaxed stress depends only on the strain rate of the curve from which relaxation commences.

Cyclic Loading

The behavior of the material under cyclic loading and repeated strain rate changes is depicted in Fig.7. At a strain of ± .2% the strain rate was switched between $10^{-3}\ s^{-1}$ and $10^{-5}\ s^{-1}$. The ensuing stress changes decrease as the material continues to harden.

Ultimately the material will reach the cyclic steady state in which the hysteresis loop is traced over provided the forcing function is not changed. Figure 8 shows the stabilized hysteresis loop at $\dot{\epsilon} = 10^{-3}\ s^{-1}$ (outside curve) and $\dot{\epsilon} = 10^{-5}\ s^{-1}$ (inside curve). At ± .2% the strain rate was switched between $10^{-3}\ s^{-1}$ and $10^{-5}\ s^{-1}$. It is seen that after an initial overshoot the hysteresis loops appropriate for the particular strain rates are reached again.

Figure 9 exhibits the cyclic creep behavior of a specimen with prior mechanical history. Initial loading to point A is followed by cyclic loading between fixed load limits and subsequent creep for one minute. After the creep period the load was cycled again at an increased load level. The increasing amount of creep during one minute with an increase in load and the decrease in accumulated strain as cycling progresses are apparent.

Strain Rate Changes after Cycling

The graph in Fig.10 depicts the behavior in a tensile test with sudden changes in strain rate between the values of $10^{-3}\ s^{-1}$ and $10^{-5}\ s^{-1}$. Prior to the tensile test the specimen had been subjected to completely reversed cycling at ± .4% until the cyclic steady-state was reached. Some overshoot upon the changes of strain rate is apparent which dies out quickly. The steady portions of the curves could be combined to give the stress-strain diagrams at the respective rates.

Data Analysis and Interpretation

The copies of actual XY recordings in Figs. 3 - 10 (exception Fig. 5) depict typical behavior of Type 304 Stainless Steel at room temperature. We have tested about ten annealed specimens extensively up to a total accumulated strain of about 15%. The following findings are of interest:

A) Repeated Loading and Unloading for Positive Stresses and Strains.

Starting from the annealed condition the material work hardens considerably, compare the stress levels in Fig. 3 with those of Fig. 6. In the steady state or "fully plastic" region the following was observed irrespective of the work hardened condition:

The "flow curves" at various strain rates are equidistant The difference $\Delta\Sigma$ between any two curves obtained at two different strain rates depends only on the respective

> strain rates and is independent of the actual value of the stress and strain. There is a nonlinear relation between $\Delta\Sigma$ and the strain rates.

Figure 11 shows $\Delta\Sigma$ (engineering stress[2)]), the stress level differences obtained at different strain rates. The stress level corresponding to $\dot{\epsilon} = 4 \times 10^{-5}$ was taken as the (arbitrary) zero value. The dots are data obtained from a specimen repeatedly loaded and unloaded to zero load between 3% and 9% strain and tested under repeated strain rate changes such as shown in Fig.6.

Also in Fig.11 are large numerals 1 - 7 which are stress changes obtained from Fig.6 (1,2), Fig.3 (3 - 6) and Fig.7 (7). The size of these numbers represents possible scatter. The stress differences 1 - 7 are plotted assuming the stress at the respective largest strain rate is on the curve traced out by the dots.

It is seen that all the points 1 - 7 coincide with the original curve within the scatter of the data. The results shown in Fig.11 are therefore in support of the statement given previously.

With regard to the relaxation behavior in tests started from the points in the "fully plastic" region we observed the following:

> In a given time period the change in relaxation stress depends only on the strain rate preceding the relaxation test and does not depend on the actual value of stress and strain.

---

2) The use of true stress would change the relation. However, differences between eng. and true stress will not alter the qualitative arguments to be made later.

Figure 12 shows the stress relaxation $|\Delta\sigma|$, measured from the start of the relaxation test, at various strain rates obtained between 11% and 12% strain. The points labelled II are taken from Fig.6. They match up nicely with the present data. The above statement is also verified by observing that the total change in stress during 600 s is equal for all four relaxation tests starting from 10^{-3} s^{-1} in Fig.6.

The presently available equipment does not allow the accurate determination of the relaxation rate. It is however possible to determine average relaxation rates by noting the stress at the beginning and the end of a time interval. These data permit the calculation of an average inelastic strain rate $|\dot{\sigma}/E|$. The vertical bars in Fig.11 show the results. In plotting the data the zero of the strain rate-change tests discussed earlier has been shifted in such a way that the strain rate change data coincide with the relaxation rate data in the 10^{-6} to 10^{-5} s^{-1} range. It is seen that the relaxation data are a natural extension of the strain rate change data.

B) <u>Strain Rate Changes after Cyclic Loading to a Cyclic Steady State.</u>

The previous results demonstrated that the material behavior was reversible, i.e. a certain strain rate change was associated with a given stress change irrespective of the actual stress and strain value and the prestrain.

Figure 10 shows the strain rate change behavior of a specimen with prior cyclic history. The strain range change designated by I is plotted in Fig.11 and falls outside the curve obtained previously for specimens with no reversed loading. We must therefore conclude that cycling to a steady state condition must have changed the strain rate change-stress change behavior.

Discussion

The experiments reported herein show considerable rate sensitivity, creep and relaxation of Type 304 stainless steel at room temperature. They are therefore not in support of the notion of rate (time) independence of metal deformation at room temperature. Plasticity is an inappropriate idealization of this material at room temperature. Other investigators have also found rate dependence in Type 304 or 316 stainless steel at room temperature, i.e., the relaxation tests of Yamada and Li (1973) and Thomas and Yaggee (1975), the dynamic tests of Albertini and Montagnani (1976 and 1977), and the creep tests by Ellis et al. (1978), Fig.3, on Type 316 SS.

Further, the gradual increase of inelasticity shown in Figs.4 and 6 does not support the notion of an abrupt boundary between elastic and inelastic deformation. It rather suggests that inelasticity is a gradually developing process which is initially extremely small but increases with increasing load.

The results of this investigation are in accord with a statement by Lubahn (1961), p.325 ... "We must recognize time-dependence as a basic characteristic of plastic deformation ..." Also in materials science plastic deformation is considered to be a rate process, e.g., Kocks, Argon and Ashby (1975). (The term plastic deformation is equivalent to the term inelastic deformation used herein.)

The behavior under strain rate changes in Fig.10 is reminiscent of the strain-rate history effect reported in dynamic plasticity, e.g., Campbell and Dowling (1970), Frantz and Duffy (1972), Klepaczko (1975) to name just a few. It should be noted that in the tests reported herein the strain rate is, within the accuracy of the servocontrol, always equal to the value given on the graphs. We see that the flow stress returns to the curve appropriate for the particular strain rate after an initial overshoot.

We have only used engineering stress in reporting the data including Figs.11 and 12. Since prestrains of about 15% are involved, the curves in Figs.11 and 12 would be slightly different if true stress would have been used. The qualitative features, i.e. stress changes for sudden changes in the strain rate are different for cyclically hardened and monotonically strained specimens, are not affected by the choice of stress measure.

The difference in the unloading behavior under rate reversal is worth noting. For strain control a very steep positive slope (larger than the elastic modulus) is obtained immediately after strain rate reversal, see Figs.7, 8 and 10. For load control a small (much less than the elastic slope) negative slope is obtained which gradually changes to a positive slope close to the elastic slope, see Fig.9. It is clear that the material can "creep" during stress-controlled unloading whereas no creep is possible during strain-controlled unloading. A similar argument applies for rate increases, see Figs.9 and 10.

The data shown in Figs.11 and 12 suggest that any microstructural changes caused only by tensile loading and unloading have no significant effect on the rate dependence of the material (specifically the stress change and the relaxation behavior). The effect of plastic deformation is noticeable in the work-hardening of the material, compare the stress levels in Figs.3 and 6. However, the strain rate change and stress damage as well as the relaxation behavior remain unaffected by monotonic loading or repeated loadings and unloadings involving only positive stresses.

During cyclic straining the work-hardening and the strain-rate change - stress change behavior change (Fig.7). Once in the cyclic steady state the material behaves in a fully reversible fashion, see Fig.8 where the transition

between the two loops corresponding to different strain rates does not cause any further changes in hardening or rate-dependence. Tests involving loading histories not exceeding the strain limits of $\pm .4\%$ show that the behavior is fully reversible. These tests included cyclic strain rate changes along the loop, repeated loading and unloading inside the loop, and creep and relaxation tests.

This fully reversible behavior in cyclic steady state entails, compared to the annealed material, an increased work-hardening and a decreased rate sensitivity, compare Figs. 3 and 10.

This result is very significant as it suggests that the effect of deformation-induced microstructural changes is almost exclusively the work-hardening as long as no load reversals are involved. However, cyclic loading causes both work-hardening and a change in the rate dependence. Evidently, the microstructural changes caused by cyclic loading are different from those induced by monotonic loading. (Indeed it is possible to distinguish monotonically and cyclically loaded specimens by examining their substructure, Moteff (1977), see also Nahm et al. (1977).)

These results are very significant for constitutive equation development. They suggest that there are regions where a metal behaves fully reversibly and according to an equation of state. The monotonic loading involving no stress reversals as well as the cyclic steady state are such examples. For monotonic loading only work-hardening and constant rate dependence must be modelled. However, if cyclic loading is involved both the work-hardening and the change in rate dependence must be accounted for. It should be noted that creep, relaxation and rate sensitivity still have the same form but are changed in "magnitude" after cyclic loading.

A piecewise nonlinear viscoelastic model as proposed by Krempl (1975), Cernocky and Krempl (1978a, 1978b) is capable of reproducing this behavior. The changes for cyclic loading are reflected in the updating rules, Krempl (1975), Liu et al. (1976). Indeed for tensile loading a good qualitative correspondence between the actual and the numerical experiments are shown by Liu and Krempl (1978).

Acknowledgement

Selection of test methods, testing and data analysis was performed by H. Moon who was unable to participate in the writing of the paper. Helpful discussions with E.P. Cernocky and M.C.M. Liu are acknowledged. The research was supported by the National Science Foundation and the Office of Naval Research. The test material was donated by ERDA now Department of Energy.

REFERENCES

Albertini, C., M. Montagnani 1976 Nuclear Eng. and Design 37, 115.

Albertini, C., M. Montagnani 1977 Report EUR 5787.e: Ispra, Italy.

Campbell, J.D., A.R. Dowling 1970 J. Mech. Phys. Solids 18, 43.

Cernocky, E.P., E. Krempl 1978a RPI Report CS 78-1, to appear in Int. J. Nonlinear Mechanics.

Cernocky, E.P., E. Krempl 1978b RPI Report CS 78-3, to appear in Acta Mechanica.

Ellis, J.R., D.N. Robinson, C.E. Pugh 1978 Nuclear Eng. and Design 47, 115.

Frantz, R.A., J. Duffy 1972 Trans. ASME J. Appl. Mech. 39E, 939.

Klepaczko, J. 1975 Mat. Sci. Eng. 18, 121.

Krempl, E. 1975 Acta Mechanica 22, 53.

Kocks, U.F., A.S. Argon, M.F. Ashby 1975 Pergamon Press.

Liu, M.C.M., E. Krempl, D.C. Nairn 1976 Trans. ASME J. Eng. Matls. and Technology 98, 322.

Liu, M.C.M., E. Krempl 1978 RPI Report CS 78-4.

Lubahn, J.D. 1961 In Mechanical Behavior of Materials at Elevated Temperature, McGraw-Hill, specifically p.325.

Moteff, J. 1977 Personal communication.

Nahm, H., J. Moteff, D.R. Diercks 1977 Acta Met. 27, 107.

Thomas, J.F., F.L. Yaggee 1975 Met. Trans. 6A, 1835.

Yamada, A.H., C.Y. Li 1973 Met. Trans. 4, 2133.

FIGURE CAPTIONS

Figure 1 — Test Specimen

Figure 2 — Stress-Strain Diagrams of Four Annealed Specimens

Figure 3 — Stress-Strain Diagrams at Different Strain Rates. At Points A the strain rate is instantaneously changed. Annealed Type 304 SS.

Figure 4 — Stress Controlled Loading with Intermittent Creep Periods. Annealed Type 304 SS.

Figure 5 — Creep Curves for the Tests Shown in Fig.4

Figure 6 — Relaxation and Strain Rate Change Tests on a Prestrained Specimen. At Points B a relaxation test of 600 s duration is started. At strains below Point C the relaxation period is 30 s.

Figure 7 — Cyclic Straining of an Annealed Specimen with Strain Rate Changes at $\pm .2\%$. The gradual hardening and the effects of rate changes are well developed.

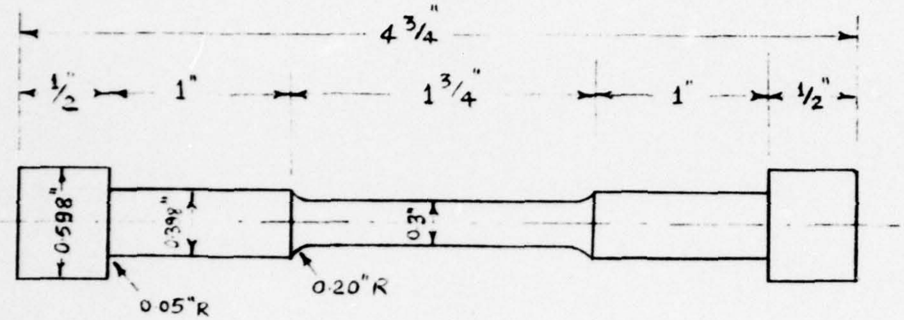
Figure 8 — Steady-State Hysteresis Loops at Strain Rates of 10^{-5} and $10^{-3}\ s^{-1}$. Note that the two loops almost coincide during the unloading portion. At Points D the strain rates were changed. The transition from one to the other hysteresis loop is fully reversible. Continuation of test in Fig.7.

Figure 9 — Cyclic Creep of a Prestrained Specimen. Creep periods of 60 s are followed by load cycling. Note the decrease in "ratchet strain" with cycles.

Figure 10 — Response to Repeated Strain Rate Changes in a Tensile Test. Cyclically prestrained specimen.

Figure 11 — Stress Change $\Delta\Sigma$ (Right-Scale) vs. Strain Rate Obtained from Strain Rate Changes in Tensile Tests (No Load Reversal). The vertical bars denote average inelastic strain rates during a relaxation test (left scale). Arabic numerals indicate stress changes measured in Figs.3, 6 and 7. Roman I denotes the stress change obtained in the tensile test of Fig.10. (All the data are plotted assuming that the stress point at the high strain rate is on the curve.) The origin of the right-hand stress scale is arranged such that the stress change curve and the relaxation curve overlap.

Figure 12 — Stress Change in Relaxation Tests as a Function of the Strain Rate of the Tensile Test Preceding the Relaxation Test. The points labelled Roman II are from Fig.6.



1 in. ≈ 25.4 mm.

FIG. 1

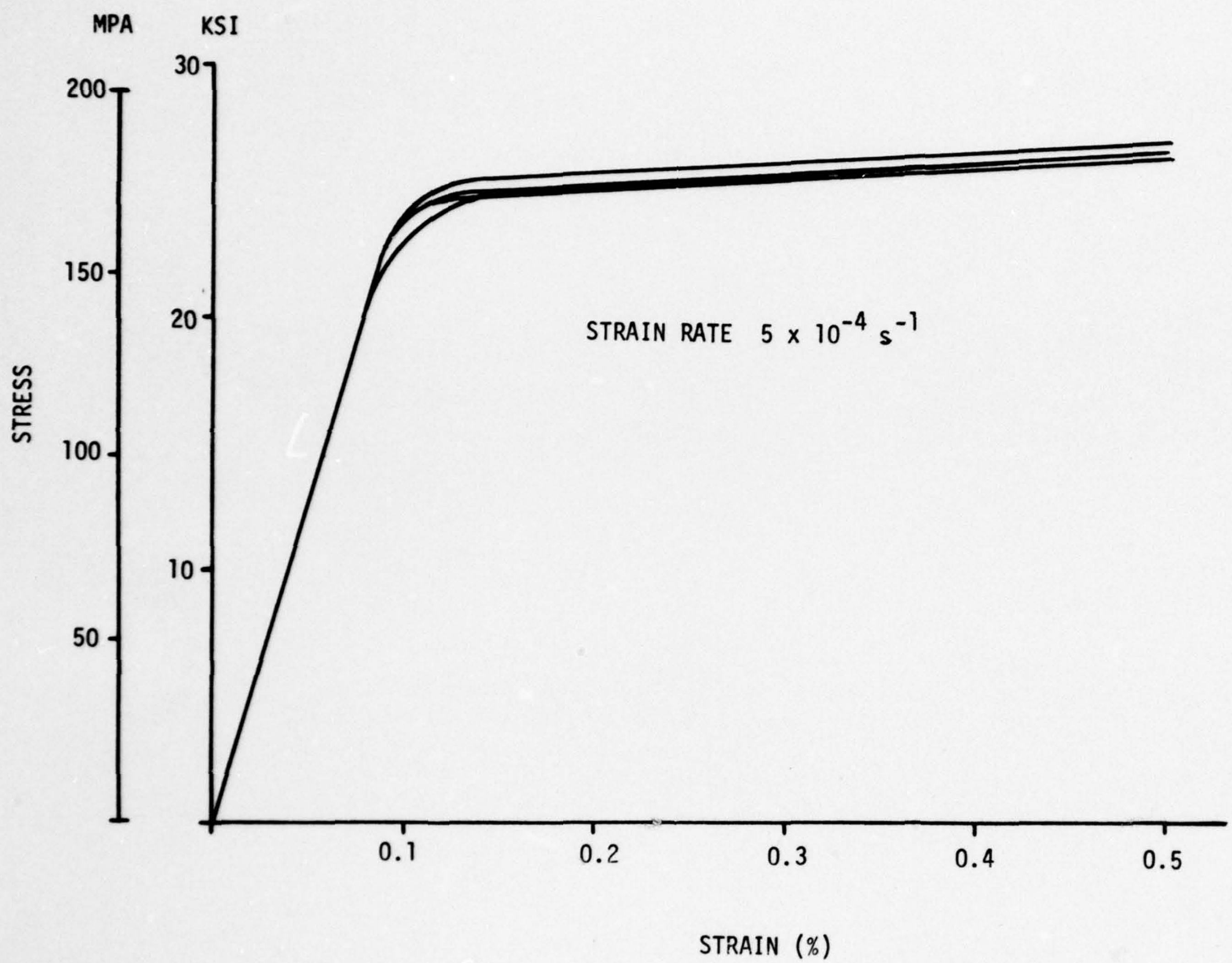
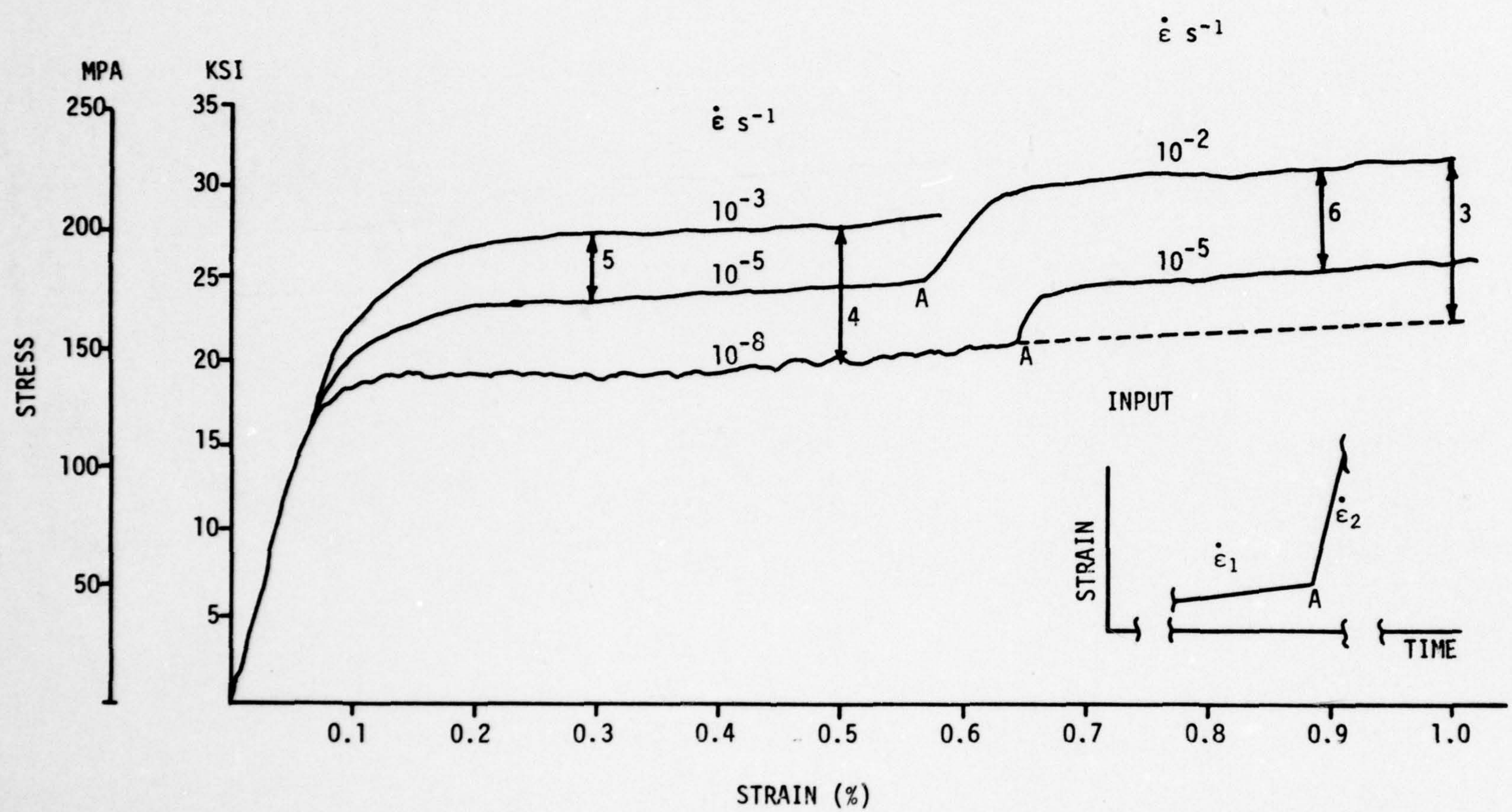

MPA
KSI
STRESS
200
150
100
50
30
20
10
STRAIN RATE 5 x 10^-4 s^-1
0.1
0.2
0.3
0.4
0.5
STRAIN (%)

FIG. 2



STRESS
MPA
KSI
250
200
150
100
50
35
30
25
20
15
10
5
$\dot{\varepsilon}$ s^{-1}
10^{-3}
10^{-5}
10^{-8}
5
4
A
10^{-2}
10^{-5}
6
3
INPUT
STRAIN
$\dot{\varepsilon}_1$
$\dot{\varepsilon}_2$
TIME
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
STRAIN (%)

FIG. 3

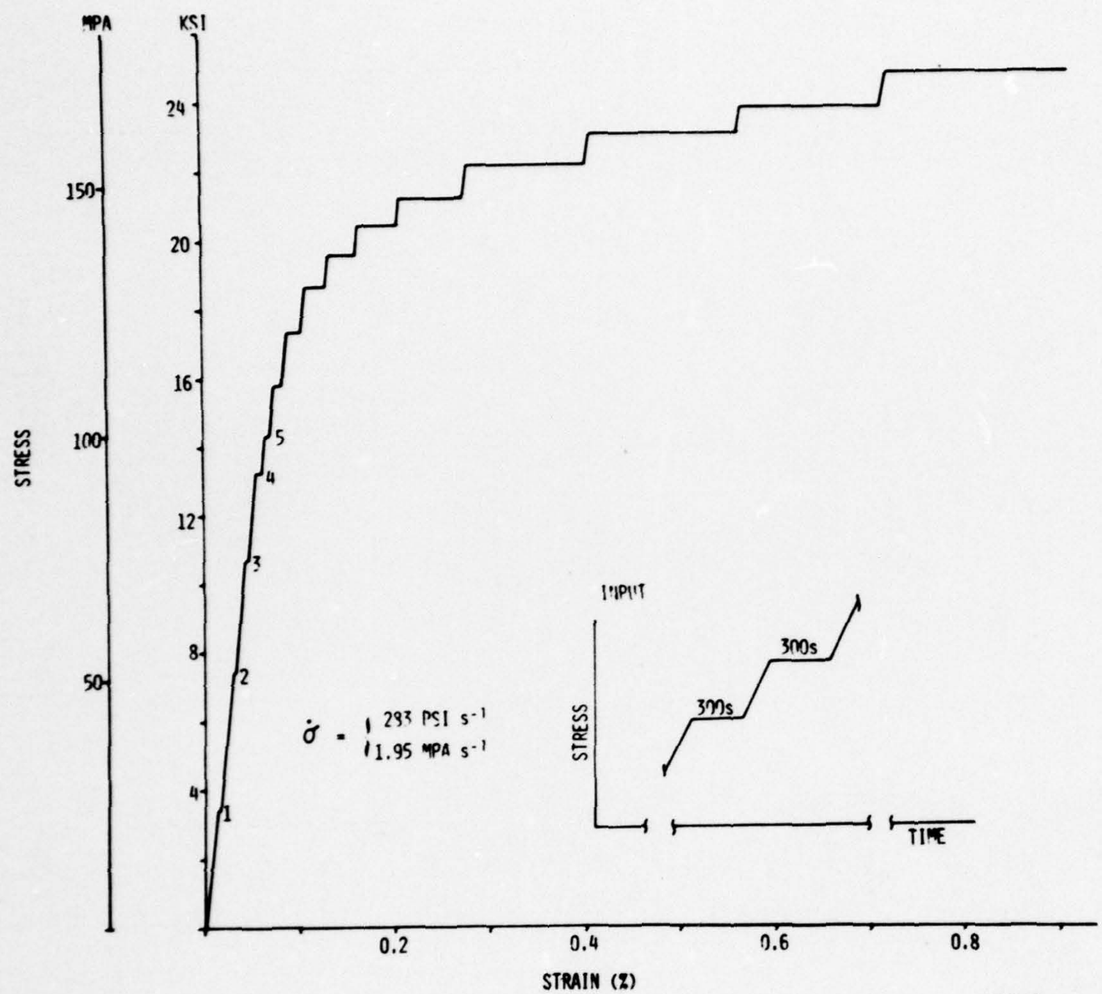
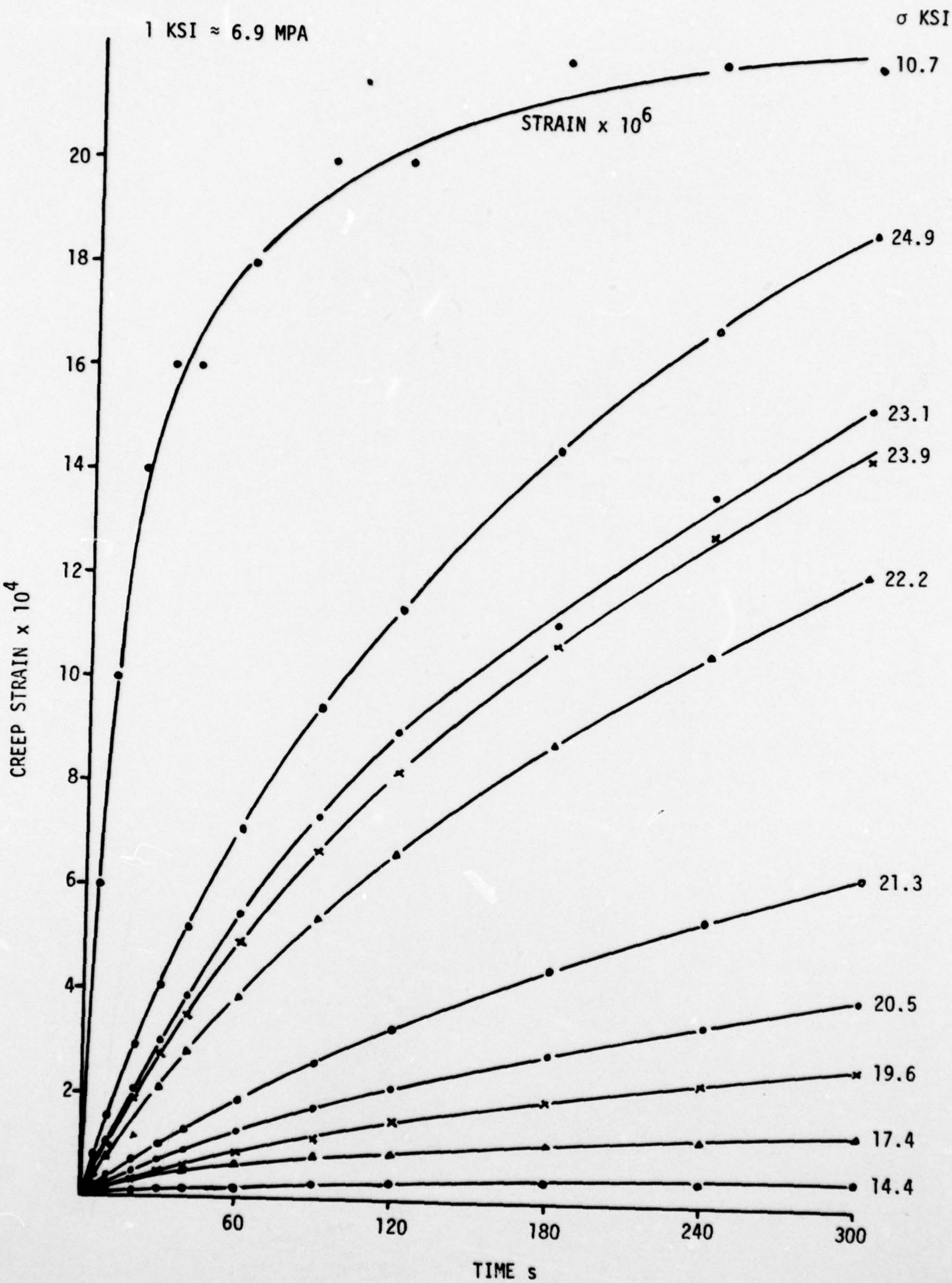

MPA
KSI
150
100
50
24
20
16
12
8
4
STRESS
1
2
3
4
5
$\dot{\sigma}$ = 283 PSI s^{-1}
1.95 MPA s^{-1}
INPUT
STRESS
300s
300s
TIME
0.2
0.4
0.6
0.8
STRAIN (%)

FIG.4



1 KSI ≈ 6.9 MPA
σ KSI
10.7
STRAIN x 10^6
24.9
23.1
23.9
22.2
21.3
20.5
19.6
17.4
14.4
CREEP STRAIN x 10^4
20
18
16
14
12
10
8
6
4
2
60
120
180
240
300
TIME s

FIG. 5

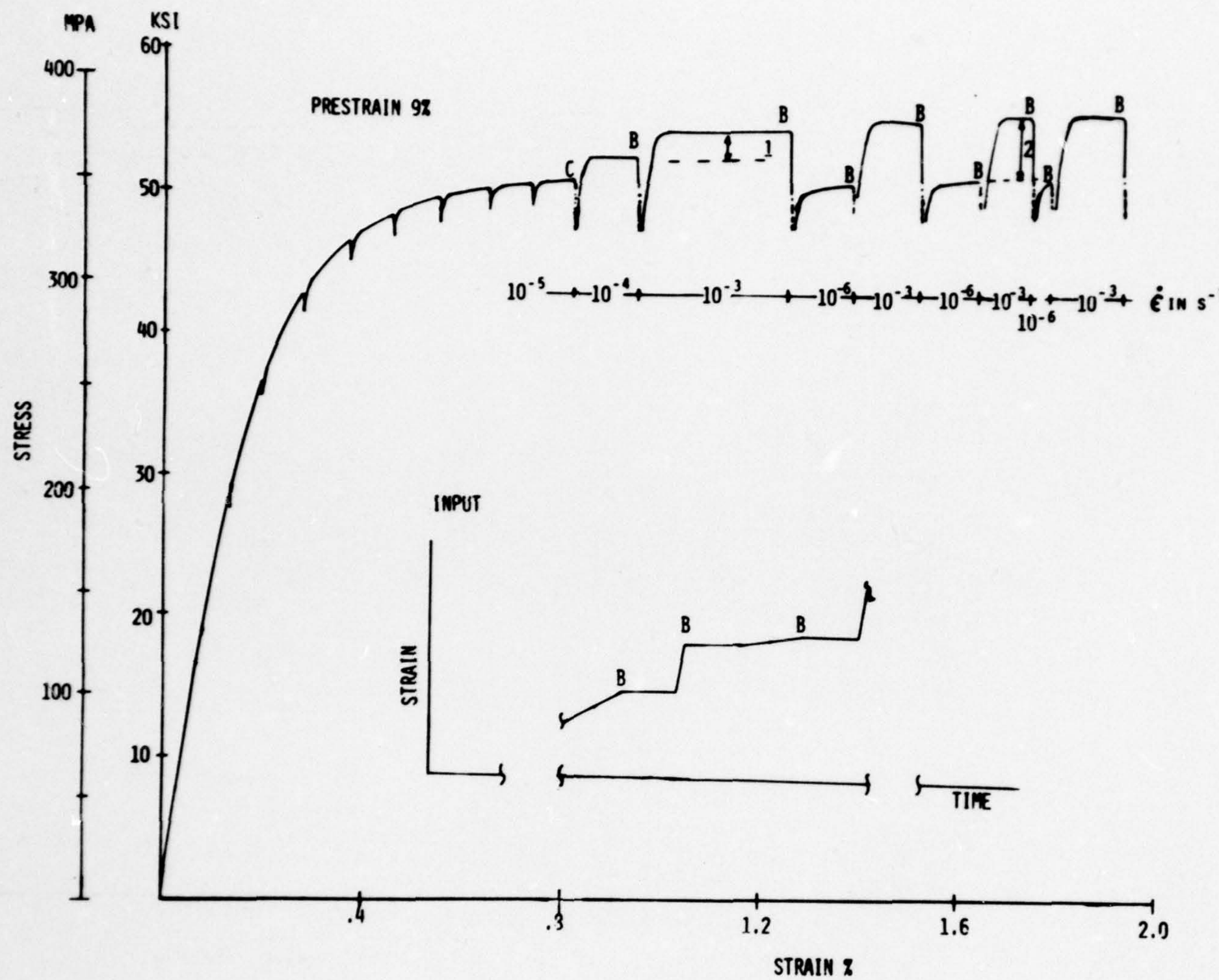
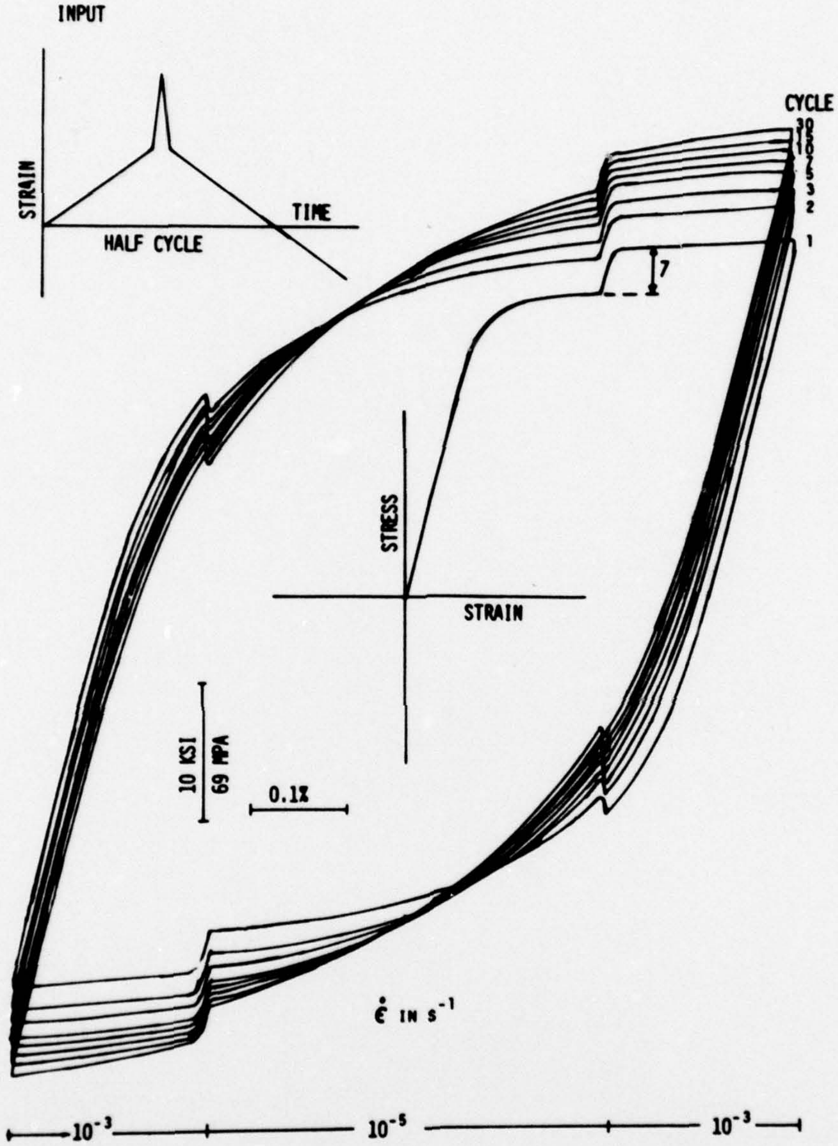
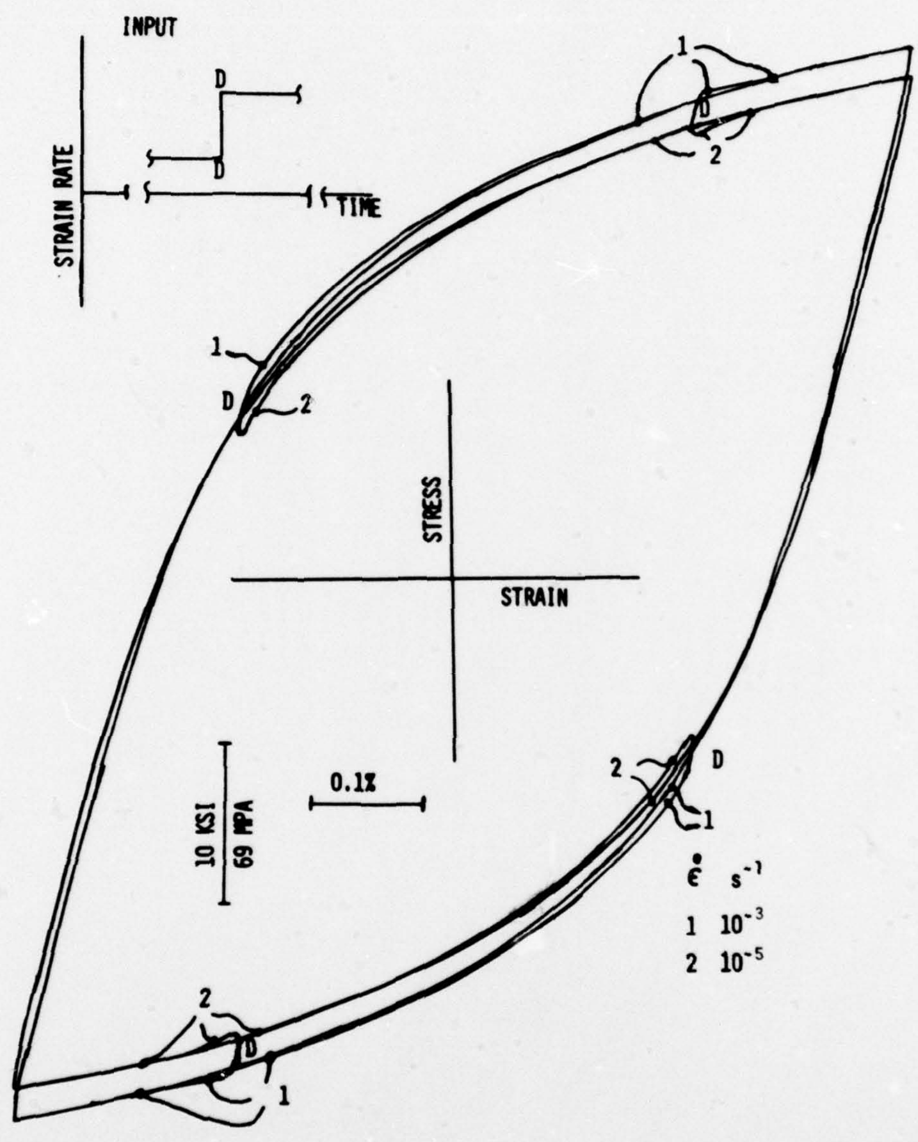

MPA
KSI
STRESS
PRESTRAIN 9%
C
B
1
2
10^{-5} 10^{-4} 10^{-3} 10^{-6} 10^{-3} 10^{-6} 10^{-3} 10^{-6} 10^{-3} $\dot{\epsilon}$ IN s^{-1}
INPUT
STRAIN
TIME
STRAIN %

FIG. 6



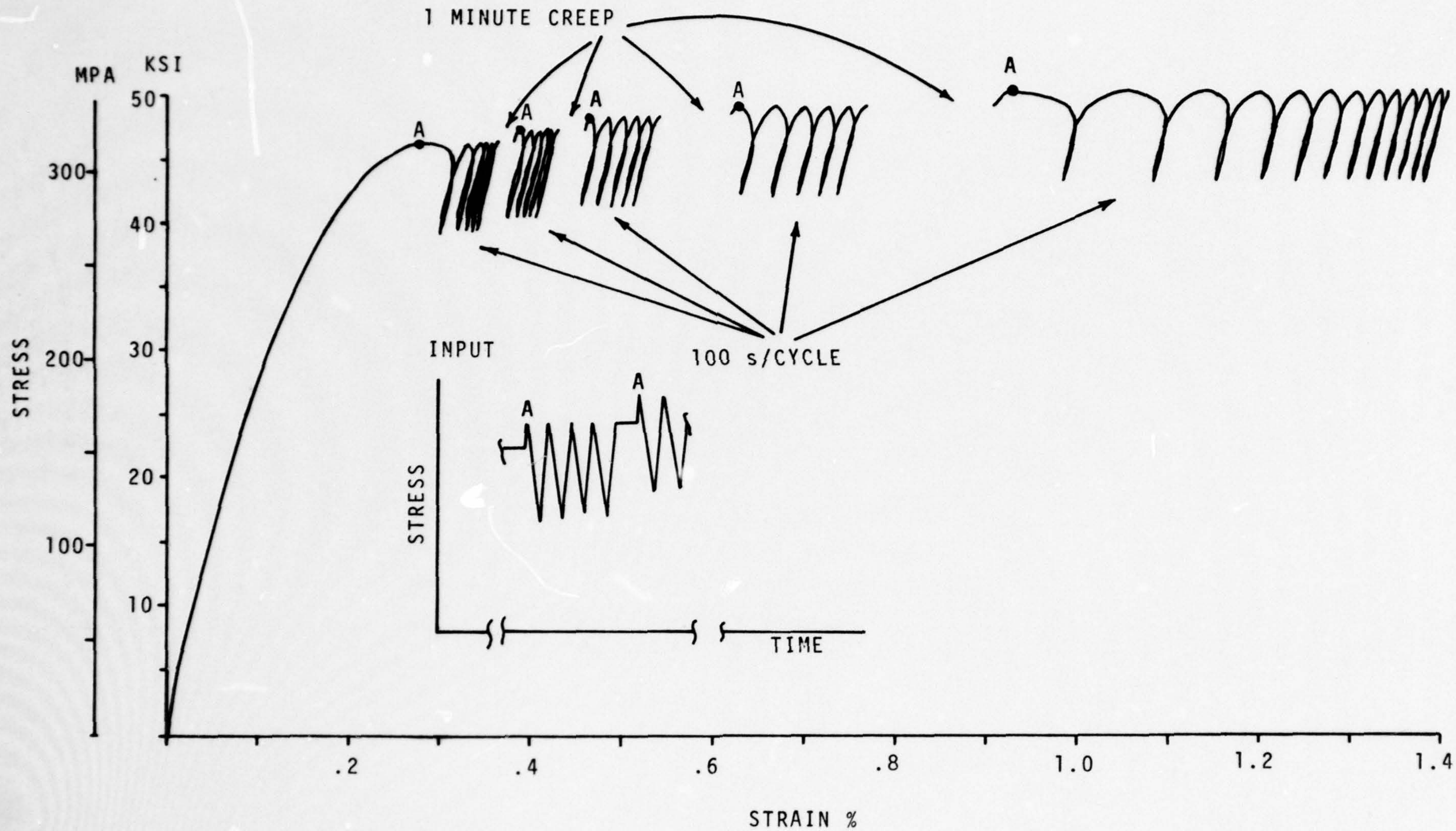
INPUT
STRAIN
TIME
HALF CYCLE
CYCLE
30
1
2
3
7
STRESS
STRAIN
10 KSI
69 MPA
0.1%
$\dot{\epsilon}$ IN s^{-1}
10^{-3}
10^{-5}
10^{-3}

FIG. 7



INPUT
STRAIN RATE
D
D
TIME
STRESS
STRAIN
1
2
D
1
2
D
2
D
1
2
D
1
10 KSI
69 MPA
0.1%
ε̇ s-1
1 10-3
2 10-5

FIG. 8



1 MINUTE CREEP
100 s/CYCLE
A
A
A
A
A
INPUT
STRESS
TIME
A
A
MPA
KSI
300
200
100
50
40
30
20
10
STRESS
.2
.4
.6
.8
1.0
1.2
1.4
STRAIN %

FIG. 9

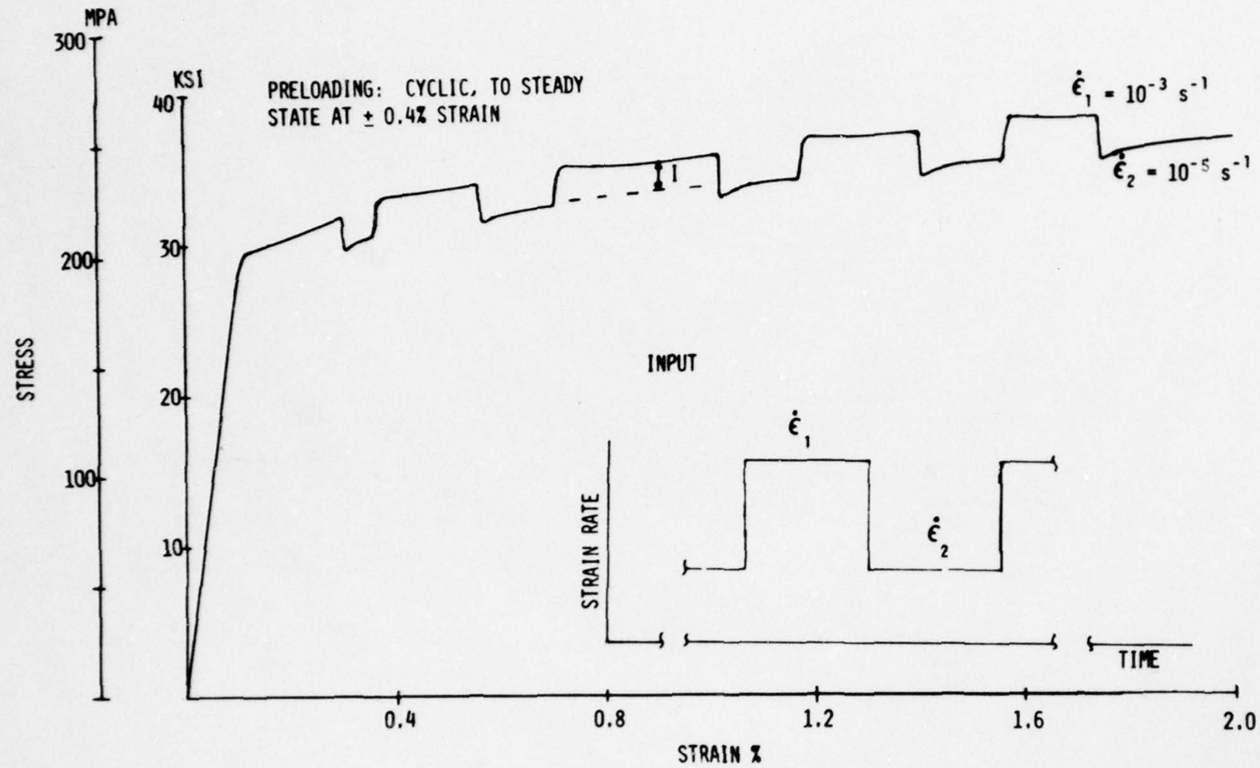

MPA
300
200
100
STRESS
KSI
40
30
20
10
PRELOADING: CYCLIC, TO STEADY
STATE AT ± 0.4% STRAIN
$\dot{\epsilon}_1 = 10^{-3}\ s^{-1}$
$\dot{\epsilon}_2 = 10^{-5}\ s^{-1}$
I
INPUT
$\dot{\epsilon}_1$
$\dot{\epsilon}_2$
STRAIN RATE
TIME
0.4
0.8
1.2
1.6
2.0
STRAIN %

FIG. 10

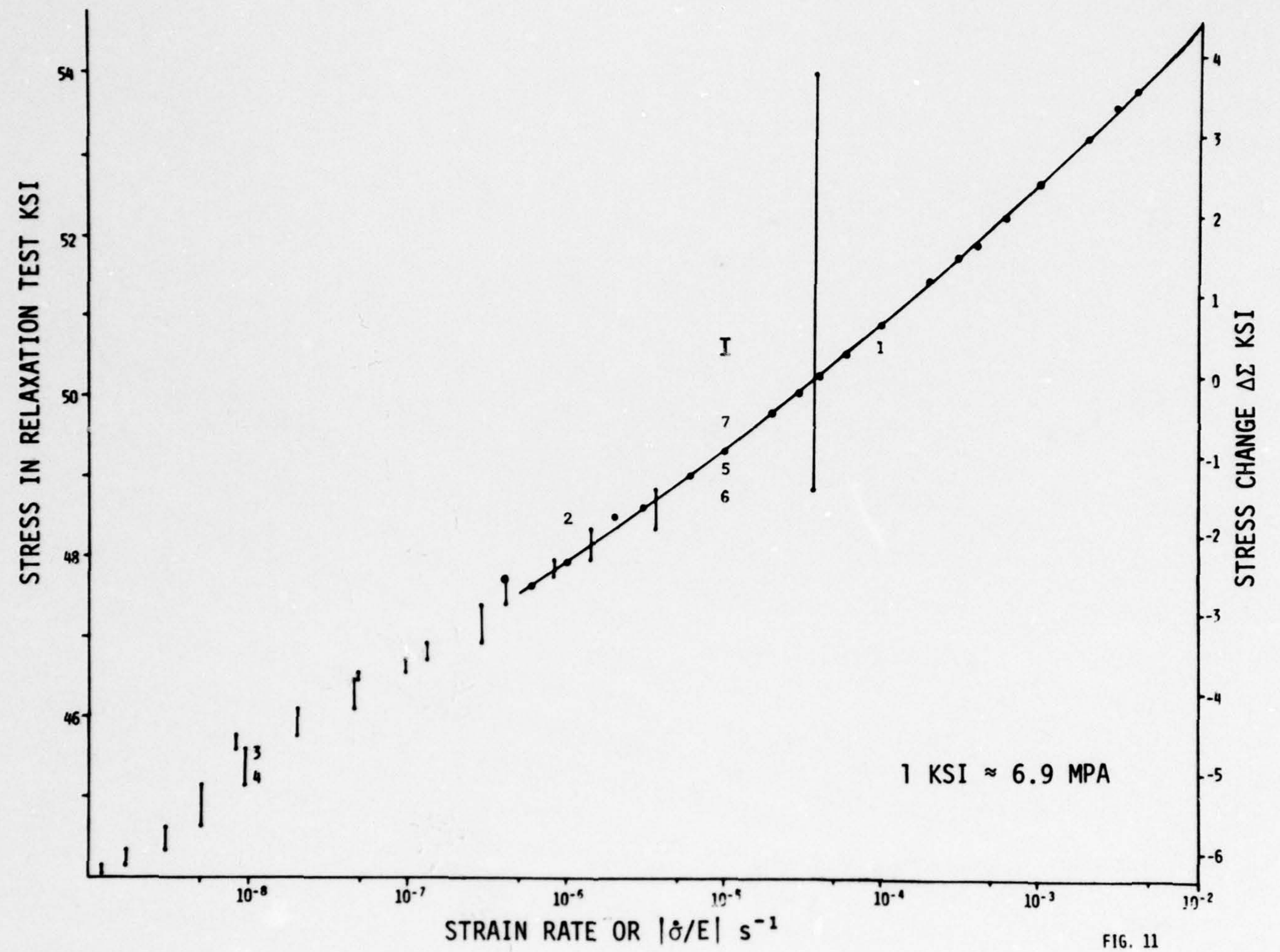
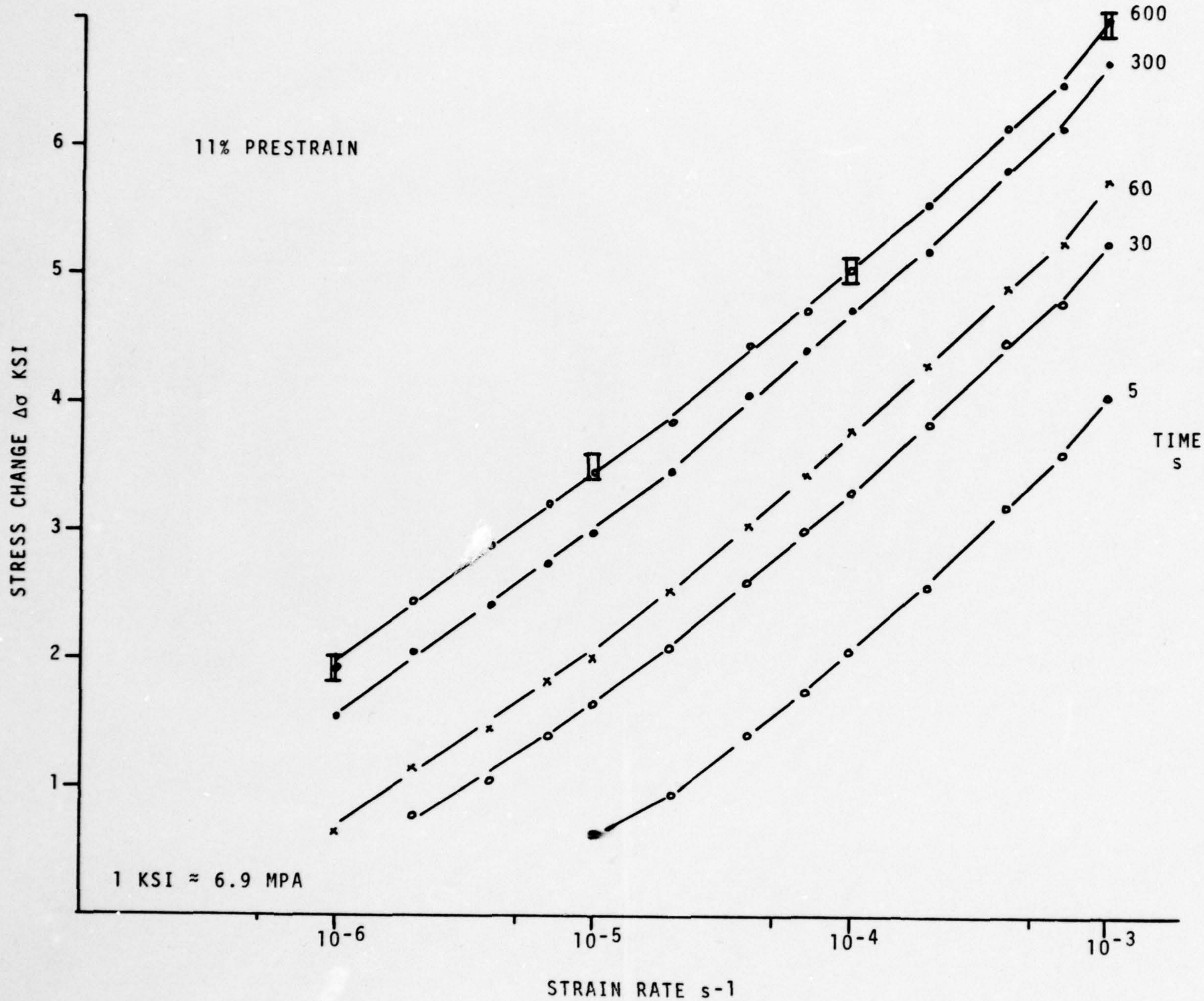

STRESS IN RELAXATION TEST KSI
54
52
50
48
46
STRESS CHANGE ΔΣ KSI
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1
2
3
4
5
6
7
1 KSI ≈ 6.9 MPA
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
STRAIN RATE OR $|\dot{\sigma}/E|$ s^{-1}

FIG. 11



11% PRESTRAIN
1 KSI ≈ 6.9 MPA
STRESS CHANGE Δσ KSI
STRAIN RATE s-1
TIME
s
600
300
60
30
5
1
2
3
4
5
6
10-6
10-5
10-4
10-3

FIG. 12

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 RPI-CS-78-5

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 Room Temperature Rate Sensitivity, Creep, and Relaxation of Type 304 Stainless Steel.

5. TYPE OF REPORT & PERIOD COVERED
9 Topical Rep[redacted]rt.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Erhard/Krempl

8. CONTRACT OR GRANT NUMBER(s)
15 N00014-76-C-0231

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Mechanical Engineering,
Aeronautical Engineering & Mechanics
Rensselaer Polytechnic Institute, Troy, NY 12181

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
NR 064-571

11. CONTROLLING OFFICE NAME AND ADDRESS
Dept. of the Navy, Office of Naval Research
Structural Mechanics Program
Arlington, VA 22217

12. REPORT DATE
11 Jul[redacted]978

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)
Office of Naval Research - Resident Representative
715 Broadway - 5th Floor
New York, NY 10003
12 29p.

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Viscoplasticity, creep, relaxation, rate-effects, stress-strain experiments, strain-rate history effects

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The uniaxial viscoplastic behavior of Type 304 stainless steel was investigated by tensile tests at various strain rates (10^{-8} to 10^{-2} s^{-1}), and by short-term creep and relaxation tests up to five hours. Instantaneous large changes in strain rate (strain-rate history effects) were also performed during monotonic and cyclic loading. A servocontrolled testing machine and displacement measurement on the specimen gage length were used for all tests.

See reverse side (over) →

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 359

Gu

The results show significant rate sensitivity, creep, and relaxation. Test histories involving loading and unloading with positive loads up to 15% strain show that the relaxation behavior in the plastic range depends only on the strain rate preceding the relaxation test and is independent of the strain magnitude. Also, the relaxation behavior is uniquely related to the stress changes corresponding to instantaneous large changes in the strain rate during tensile tests. Completely reversed strain controlled loading gradually changes the stress-change strain-rate-change behavior. Annealed specimens and specimens loaded to a cyclic steady state differ not only in their work hardening characteristic but also in their rate-dependent behavior. In the cyclic steady state different hysteresis loops are traced for different strain rates with fully reversible transitions from one hysteresis loop to the other under strain-rate changes. These results support the notion that viscoplasticity can be represented by piecewise nonlinear viscoelasticity.